

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

الحمد لله الذي جعل القرآن الكريم آية في كتابه

**Shiraz University**  
**Faculty of Agriculture**  
**Department of Horticultural Sciences**

**Seminar Topics:**  
**Mechanisms of Plant Defense against Insect**  
**Herbivores**

**By:**  
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# PLANT signaling & behavior

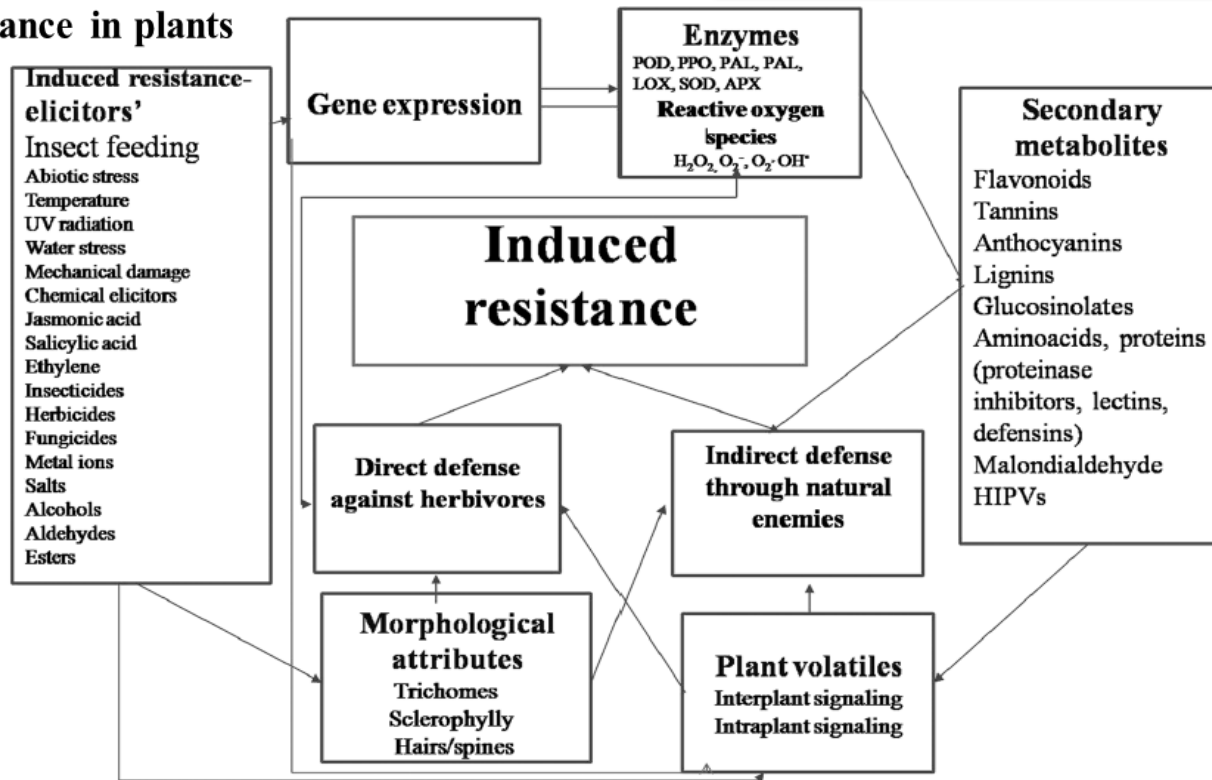
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## Mechanisms of Plant Defense against Insect Herbivores

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### Mechanism of induced resistance in plants



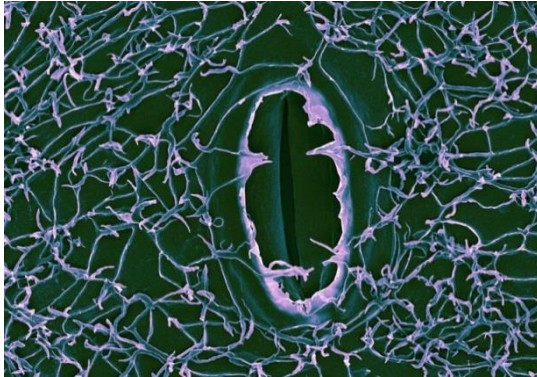
**first** physical barrier to feeding by the herbivores

leaf surface wax

cell wall thickness and lignification

trichomes

spines



and the secondary metabolites such act as toxins and also affect growth, development, and digestibility reducers form the **next** barriers that defend the plant from subsequent attack.

**Synergistic** effect among different defensive components

In **tomato**

alkaloids, phenolics, proteinase inhibitors (PIs), and the oxidative enzymes

In *Nicotiana attenuata*

→ trypsin proteinase inhibitors and nicotine Expression → **Spodoptera exigua**



damage by **adult leaf beetles**, *Phratora vulgatissima* L. in *Salix cinerea* L. induced higher **trichome** density in the new leaves developing thereafter.



Increase in **trichome** density after insect damage has also been reported in *Lepidium virginicum* L. and *Raphanus raphanistrum* L.



*Lepidium virginicum* L



*Raphanus raphanistrum* L

In black mustard, **trichome** density and **glucosinolate** levels were elevated after feeding by *Pieris rapae* (L.)



**Trichome** density increased in *Alnus incana* Moench as a result of damage by beetles.





The increase in trichome density in response to herbivory is typically between **25–100%**, however, there are cases where **500–1000%** increase in trichome density has been reported.

Changes in trichome density occur within days or weeks after insect damage

A positive correlation has been observed between **natural enemies'** abundance and **trichome density**. Trichome exudates also serve as extra floral nectar (EFN) for **scelonid egg parasitoid**, of **squash bugs**, *Gryon pennsylvanicum* Ashmead.





### Secondary metabolites and plant defense

The defensive (secondary) metabolites can be either constitutive stored as inactive forms or induced in response to the insect or microbe attack. The former are known as **phytoanticipins** and the latter as **phytoalexins**.

The classic examples of **phytoanticipins** are **glucosinolates** that are hydrolyzed by **myrosinases** (endogenous  $\beta$ -thioglucoside glucohydrolases) during tissue disruption.

Other phytoanticipins include **Benzoxazinoids (BXs)**, which are widely distributed among **Poaceae**. Hydrolyzation of **BX-glucosides** by **plastid-targeted  $\beta$ -glucosidases** during tissue damage leads to the production of **biocidal aglycone BXs**, which play an important role in plant defense against insects.

**Phytoalexins** include **isoflavonoids**, **terpenoids**, **alkaloids**, etc., that influence the performance and survival of the herbivores.

The secondary metabolites not only **defend** the plants from different stresses, but also increase the **fitness** of the plants.

It has been reported that **maize** HPR to **corn earworm**, *Helicoverpa zea* (**Boddie**) is mainly due to the presence of the secondary metabolites **C-glycosyl flavone maysin** and the **phenylpropanoid** product, **chlorogenic acid**.





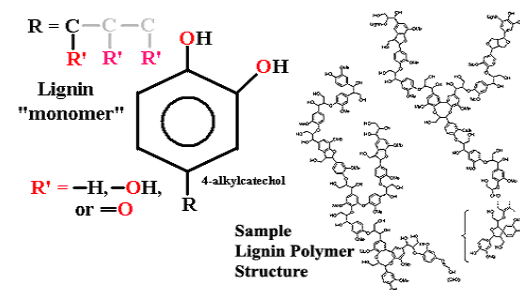
4, 4-dimethyl cyclooctene has been found to be responsible for shoot fly *Atherigona soccata* resistance in sorghum *S. bicolor*



### Plant phenolics

Phenols act as a defensive mechanism not only against herbivores, but also against microorganisms and competing plants. Qualitative and quantitative alterations in phenols and elevation in activities of oxidative enzyme in response to insect attack is a general phenomenon.

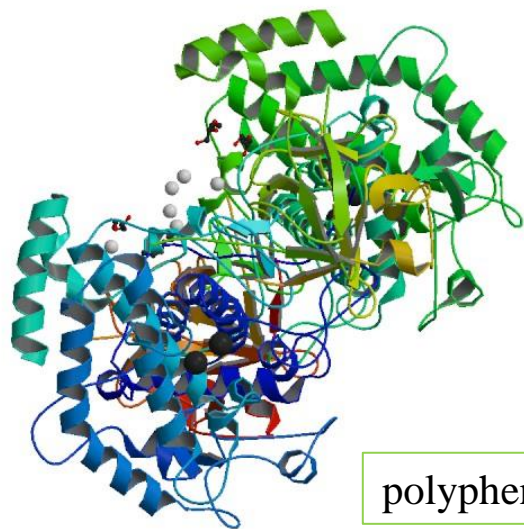
**Lignin**, a phenolic heteropolymer plays a central role in plant defense against insects and pathogens.



Increase in **expression** of lignin associated genes (*CAD/CAD*-like genes) in plants infected with pests

### mechanism

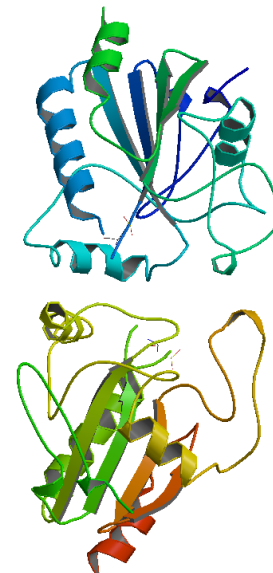
Oxidation of phenols catalyzed by polyphenol oxidase (**PPO**) and peroxidase (**POD**) is a potential defense mechanism in plants against herbivorous insects.



polyphenol oxidase

↓

**Quinones** formed by oxidation of phenols bind covalently to leaf proteins, and inhibit the protein digestion in herbivores.



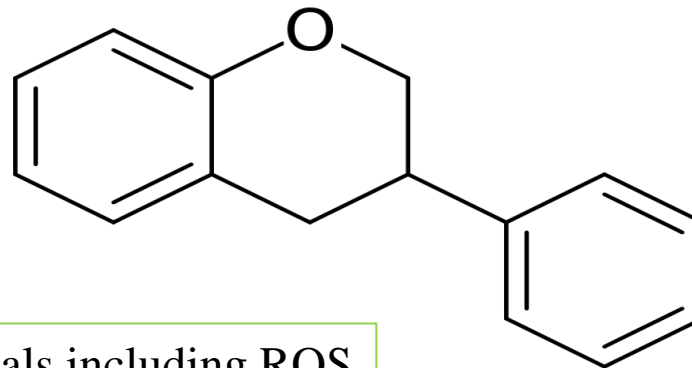
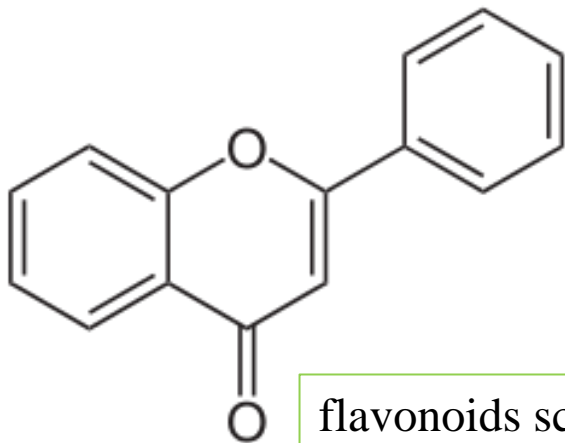
peroxidase

Phenols also play an important role in cyclic reduction of reactive oxygen species(**ROS**) such as **superoxide** anion and **hydroxide** radicals,  $\text{H}_2\text{O}_2$ , and **singlet oxygen**, which in turn activate a cascade of reactions leading to the activation of defensive enzymes.



**Simple phenolics** act as antifeedant to insect herbivores such as *Operophtera brumata* (L.) in *Salix* leaves, and there is a negative correlation between the salicylate levels and the larval growth.

## Flavonoids & isoflavonoids



flavonoids scavenge the free radicals including ROS

Flavonoids are divided into various classes that include **anthocyanins**, **flavones**, **flavonols**, **flavanones**, **dihydroflavonols**, **chalcones**, **aurones**, **flavan**, and **proanthocyanidins**.

More than 5000 flavonoids have been reported in plants.

flavones 5-hydroxyisoderricin

7-methoxy-8-flavanone

5-methoxyisoronchocarpin

*Tephrosia villosa* (L.)



*T. purpurea* (L.)



*T. vogelii* Hook



*Spodoptera exempta* (Walk.)



*Spodoptera littoralis* Bios.



in *Arabidopsis*



against *Spodoptera frugiperda*



feeding deterrents to insects

Angustone A  
lcoisoflavone B  
angustone B  
angustone C  
Isoflavones  
lcoisoflavone A  
luteone  
wighteone



antifungal activity against the fungi, *Colletotrichum gloeosporioides* (Penz.) and *Cladosporium cladosporioides* (Fres.)

## Isoflavonoids

Judaicin

judaicin-7-*O*-glucoside

2-methoxyjudaicin

maackiain



chickpea



*Helicoverpa armigera*

Cyanopropenyl glycoside & alliarinoside



*Helicoverpa*



**Tannins**



binding to the proteins



reduce nutrient absorption



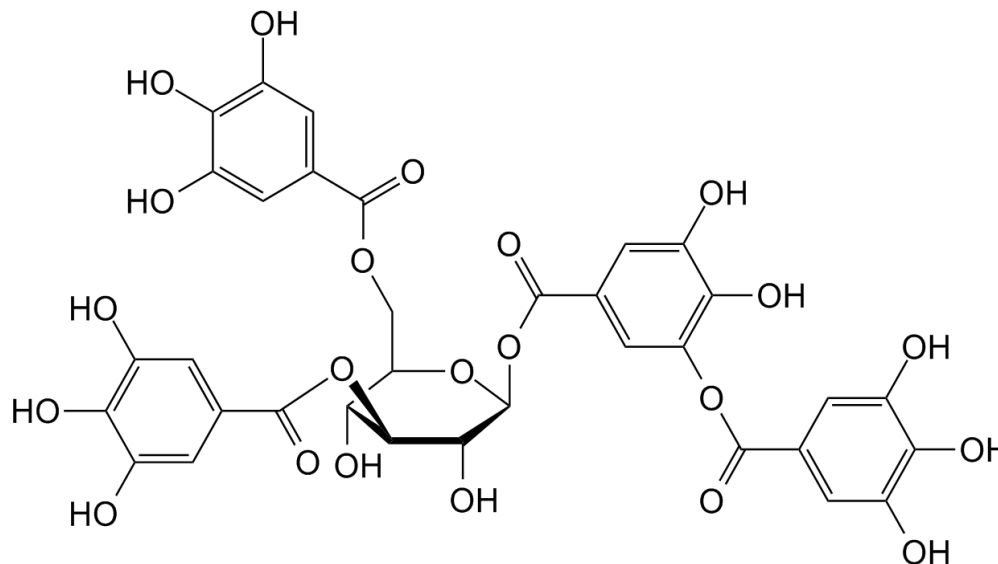
midgut lesions



chelate the metal ions



Reducing bioavailability to herbivores



**Procyanindin polymers** have been found as feeding deterrent to *Aphis craccivora* (Koch) in **groundnut**



Tannins



Alaska paper birch



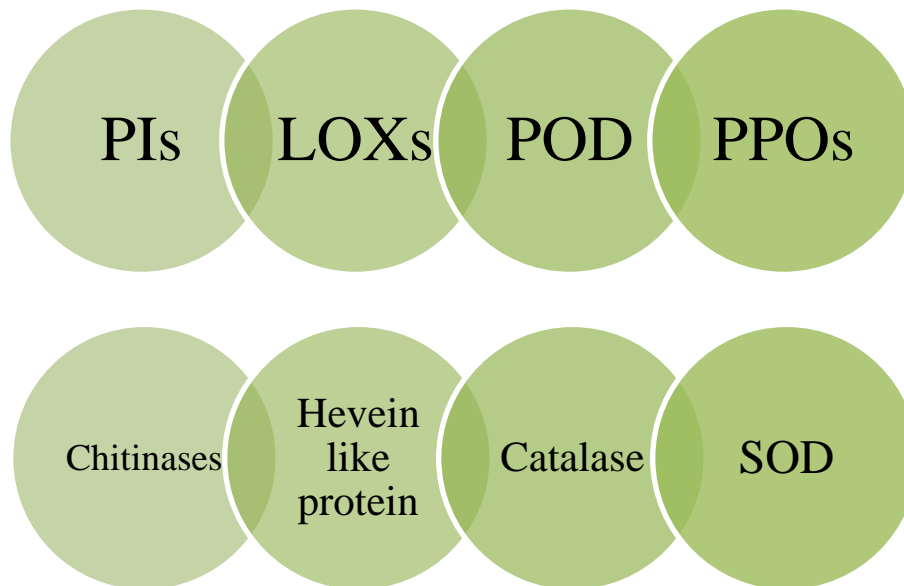
reduce pupal mass & larvae

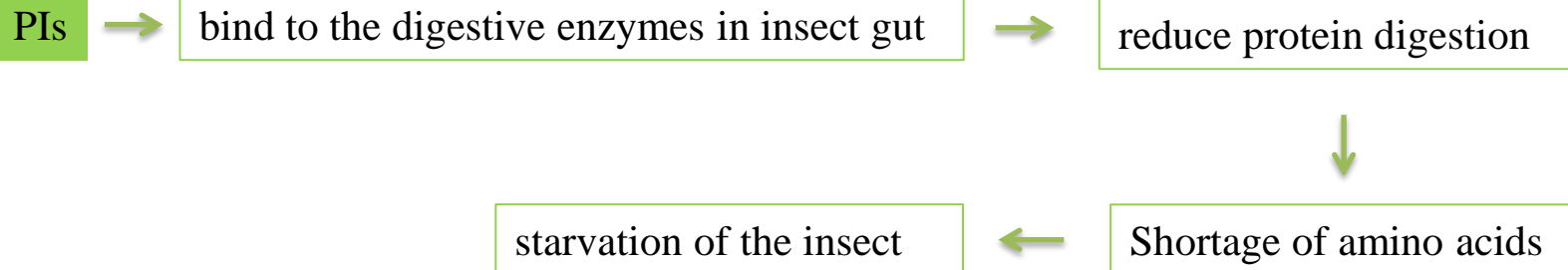


*Rheumaptera hastata* (L.)



Plant defensive proteins against insect pests





Many classes of PIs are induced in plants in response to stresses. Kunitz proteinase inhibitors (**KPIs**) are the serine Pis (SPIs), which are among the most strongly upregulated defense genes in response to wounding or herbivore feeding in plants.

Various KPIs allow plants to deal with **multiple generations** of insects by providing a **genetic storehouse** of varied Pis.

PIs

*Sorghum bicolor* & Tomato

*Schizaphis graminum*

*Gossypium hirsutum*

*Helicoverpa armigera*

*Solanum nigrum*

*Manduca sexta* & *Spodoptera littoralis*



PIs

*Nicotiana attenuata*

*Spodoptera exigua*



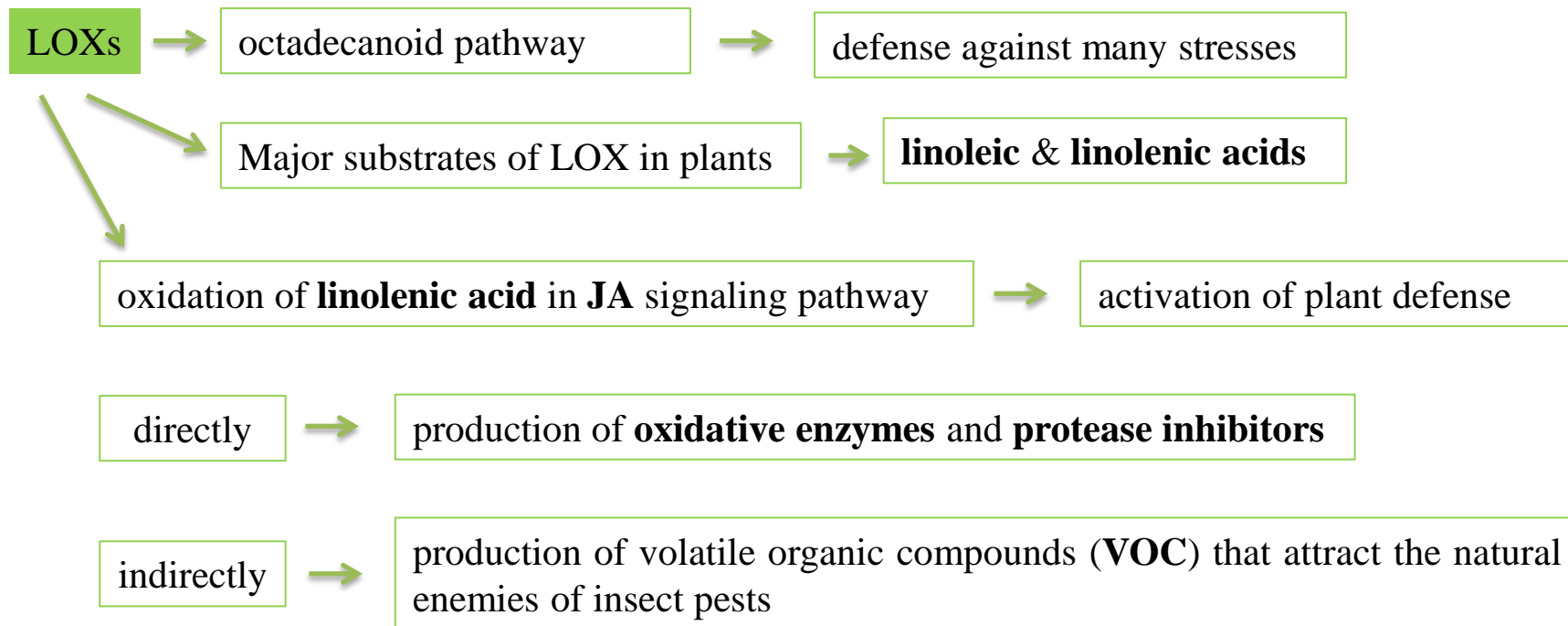
*Transgenic Arabidopsis/oil seed rape*

*Plutella xylostella*

*Transgenic Arabidopsis/ tobacco*

*Mamestra brassicae*





LOXs

*Cucumis sativus*



*Spodoptera littoralis*

*Nicotiana attenuata*



*Bemisia tabaci*

*Alnus glutinosa*



*Agelastica alni*



LOXs

Wheat



*Sitobion avenae*

Tomato



*Macrosiphium euphorbiae* *Myzus persicae*

*Nicotiana attenuata*



*Myzus nicotianae*





PODs



scavenges the ROS

Production of **phenoxy** and other oxidative radicals



reduce the plant digestibility

A number of process are regulated by PODs that have direct or indirect role in plant defense, including **lignification**, **suberization**, **somatic embryogenesis**, **auxin metabolism**, and **wound healing**.

POD

*Alnus glutinosa*



*Agelastica alni*

*Arabidopsis*



*Bemisia tabaci* (whitefly)

*Buffalograss*



*Blissus oxidus*



POD

Poplar



*Lymantria dispar*

Medicago sativa



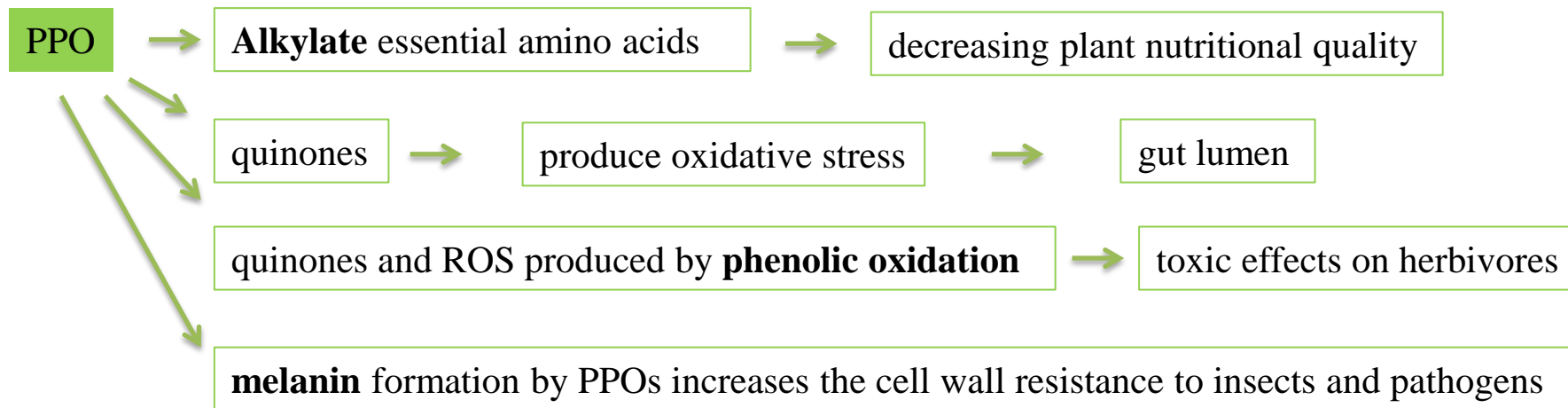
*Aphis medicaginis*

Rice



*Spodoptera frugiperda*





## PPOs

Tomato



*Manduca sexta*



Buffalograss



*Spodoptera frugiperda*

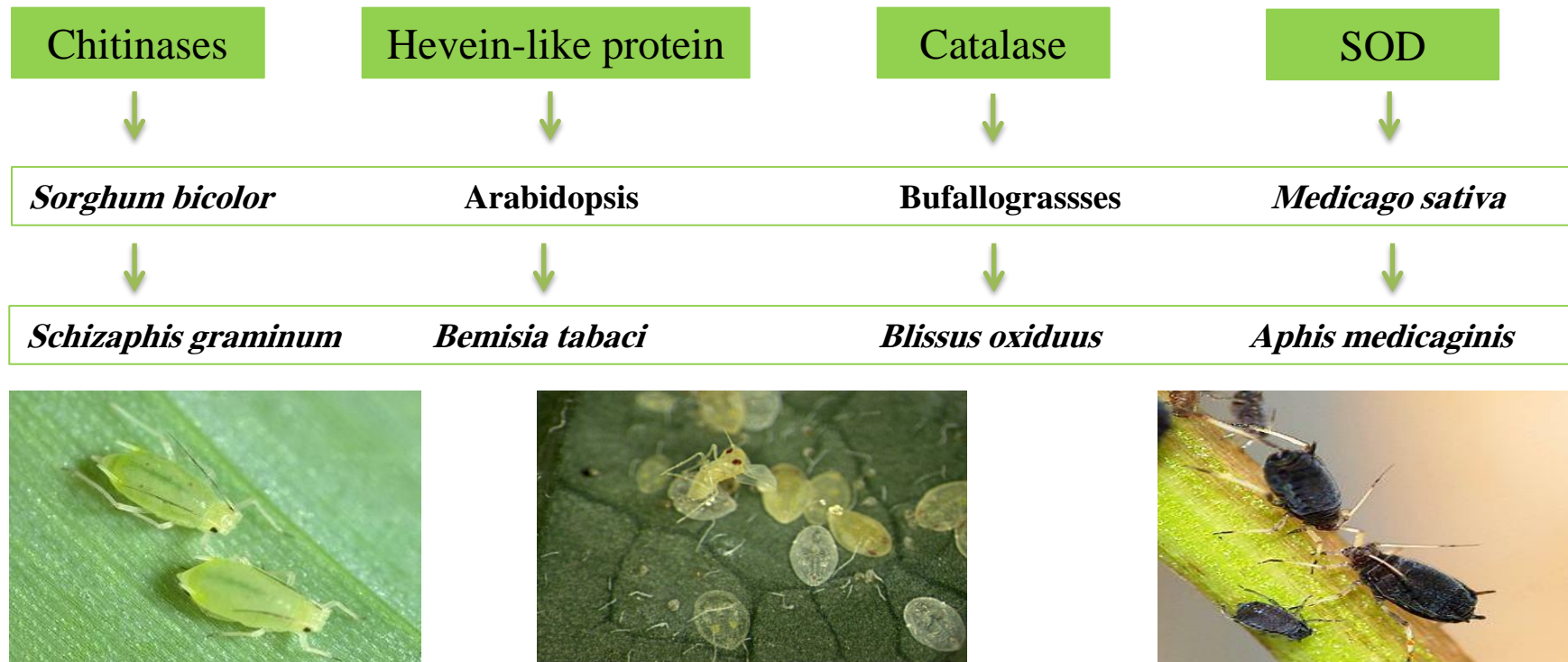


Tomato



*Helicoverpa armigera*







### Plant lectins

act as antinutritive and/or toxic substances by **binding to membrane glycosyl groups**

Lectin	Plant	Insect
<i>Allium sativum</i> leaf lectin	Tobacco Chickpea	Aphids <i>Aphis craccivora</i>
Jacalin-like lectins <i>Bauhinia monandra</i> leaf lectin	Wheat Tobacco	<i>Mayetiola destructor</i> <i>Anagasta kuehniella</i> <i>Zabrotes subfasciatus</i> <i>Callosobruchus maculatus</i>
Snowdrop lectin	Rice Wheat Arabidopsis	Aphids <i>Nilaparvata lugens</i> Aphids <i>Pieris rapae</i> , <i>Spodoptera littoralis</i>
Nictaba-related lectins NICTABA, PP2	Tobacco	<i>Spodoptera littoralis</i> , <i>Manduca sexta</i> , <i>Acyrtosiphon pisum</i>
<i>Arum maculatum</i> lectin		<i>Lipaphis erysimi</i> , <i>Aphis craccivora</i>

## Herbivore induced plant volatiles (HIPV)

*Spodoptera frugiperda* infestation in **rice** induces emission of about 30 volatiles, including **MeSA** and **MeBA**, which are highly attractant to the natural enemies of *S. frugiperda*, such as, ***Cotesia marginiventris***.



## Herbivore induced plant volatiles (HIPV)

Sesquiterpene (E)- $\beta$ -caryophyllene produced by **maize roots** in response to feeding by the larvae of *Diabrotica virgifera virgifera* attracts the nematode *Heterorhabditis megidis*.



## Role of phytohormones in induced resistance in plants

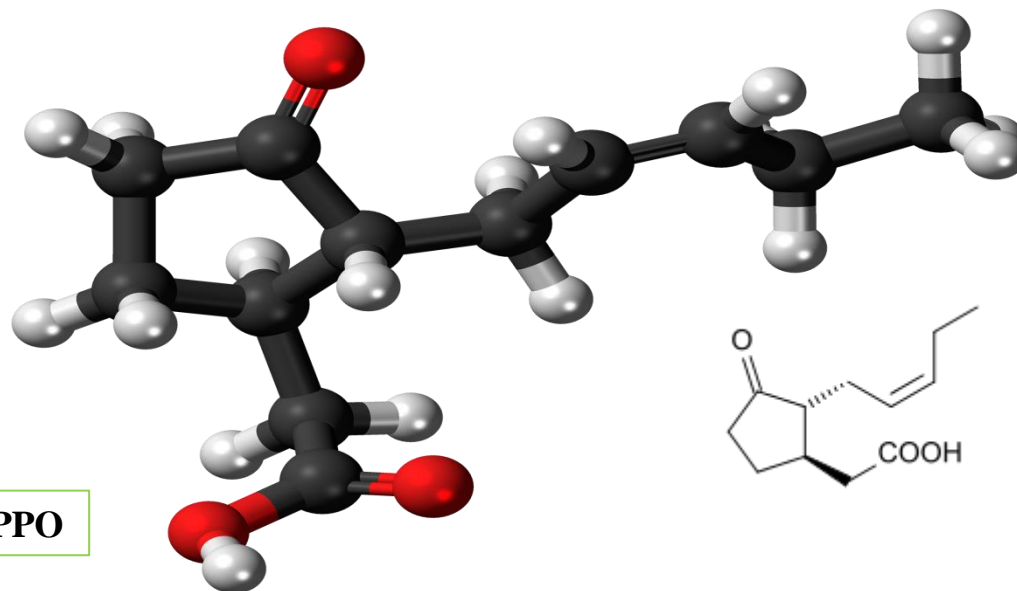
Most of the plant defense responses against insects are activated by signaltransduction pathways mediated by **JA**, **SA**, and **ethylene**.

### Jasmonic acid

JA is derived from **linolenic acid** through **octadecanoid** pathway

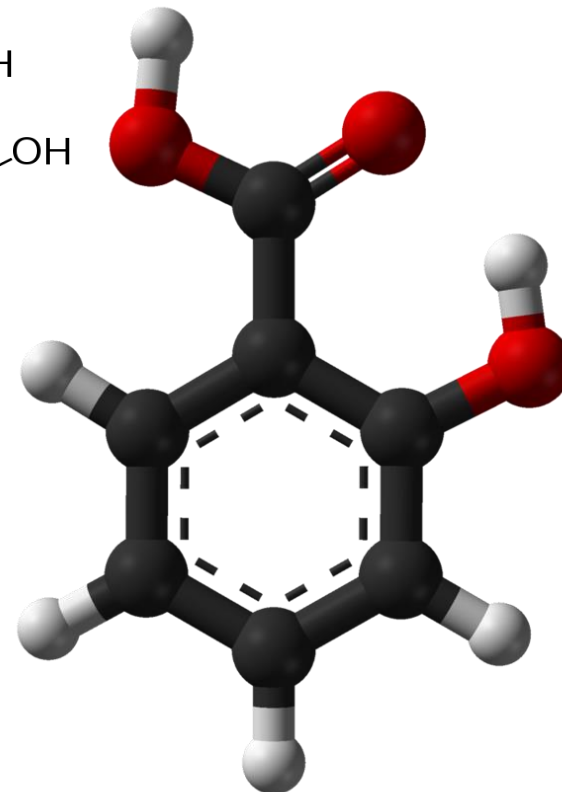
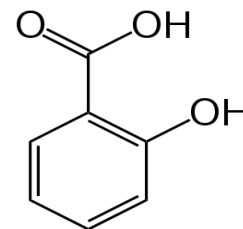
Produce of the EFN

induces the defense enzymes such as **POD** & **PPO**



### Salicylic acid

Production of **ROS** by SA pathway has been proposed to induce resistance in plants against insect pests, e.g., in **tomato** plants against *Helicoverpa armigera*.



### Salicylic acid

**H<sub>2</sub>O<sub>2</sub>** induced by SA in plants defends them against various insect pests since H<sub>2</sub>O<sub>2</sub> actively damages the **digestive system** of insects leading to reduced growth and development.

SA signals the release of **plant volatiles** that attract the **natural enemies** of insect pests, e.g., **Lima bean** and **tomato** plants infested by **spider mite** attract the natural enemies of spider mite



### Ethylene

directly and indirectly

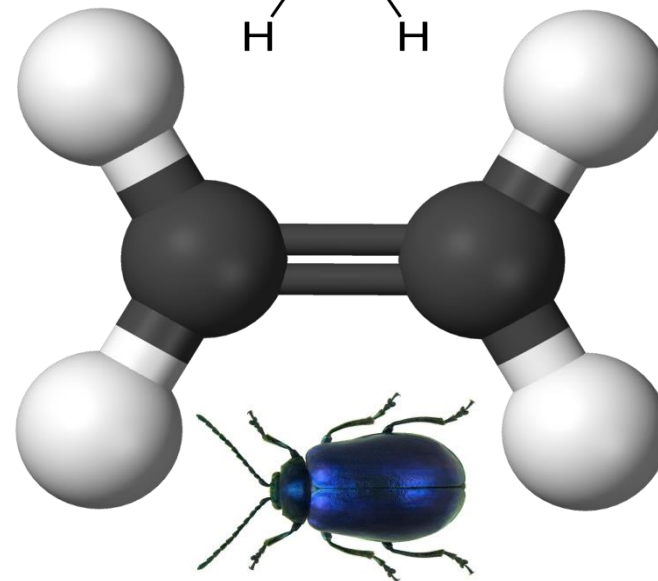
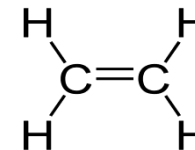


limited reports on its role in indirect defense

Infestation by *Agelastica alni* induced the emission of **ethylene** and release of **mono-, sesqui and homoterpenes** in *Alnus glutinosa* L. leaves.



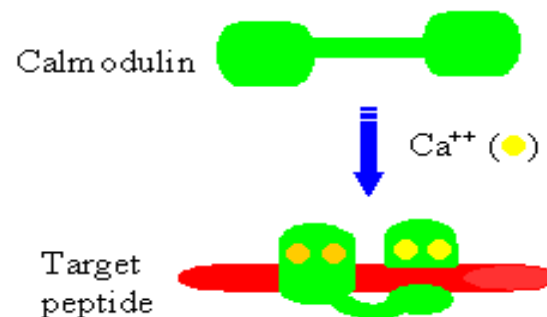
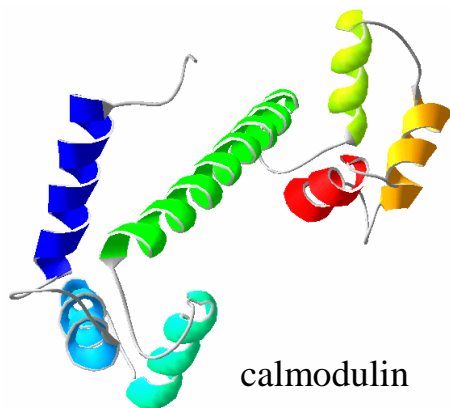
induced the emission of volatiles induced by **volicitin**, **JA** or **(Z)-3-hexen-ol** in **maize**.



## Role of Calcium ions ( $\text{Ca}^{2+}$ ) in plant defense

second messenger

upon insect attack, the cytosolic  $\text{Ca}^{2+}$  increases, which in turn activates the **calcium-sensing proteins** such as **calmodulin**, **calmodulin-binding proteins**, and **calcium-dependent protein kinases (CDPKs)** that promote the signaling events such as, **phosphorylation** and **transcriptional change**.





## Role of reactive oxygen species (ROS) in plant defense

Among all the ROS, high stability and freely diffusible **H<sub>2</sub>O<sub>2</sub>**

Following insect attack, **ROS accumulate** in apoplastic as well as in symplastic regions, besides their main concentration in exocellular **matrix**, **peroxisomes/mitochondria**, and **plasma membrane**.

suggesting that ROS act as **secondary messengers** to control gene expression

ROS mediate the **defensive gene activation** and **establish additional defenses** by regulating the transcription and/or by **interacting** with other signal components like **phosphorylation** in plant systems in response to a variety of stresses.

Induction of H<sub>2</sub>O<sub>2</sub> has been studied in **oat**, **wheat**, **barley** and **groundnut** against *Diuraphis noxia*, *Rhopalosiphum padi*, *Schizaphis graminum* Rond., *Helicoverpa armigera* & *Spodoptera litura*.





### Conclusion

Plants respond to herbivory through various **morphological**, **biochemicals**, and **molecular mechanisms** to counter/offset the effects of herbivore attack.

defense against the herbivores are **wide-ranging**, highly dynamic, and are mediated both by **direct** and **indirect** defenses.

Induced resistance could be exploited as an important tool for the pest management to **minimize** the amounts of **insecticides** used for pest control.

THANK YOU

